TORNADO OF MAY 24, 1927, AT ST. JOSEPH, MO.

By W. S. BELDEN

A tornado advanced in an easterly direction through St. Joseph, Mo., from the Missouri River, beginning at about 5:18 a. m. on the 24th. Its destructive path was approximately two blocks wide, but not continuous. Much of the greater part of the destruction to property was in a business portion of the city from Third and Sylvanie Streets nearly due east to High School Hill. Within this distance of two-thirds of a mile many large buildings were seriously damaged, roofs and walls being destroyed. After passing over the hill the course of the tornado was to the southeastward, with considerable damage for several blocks in the residential district, beginning at Sixteenth and Olive Streets. Then after another interval of about half a mile, with only slight damage, the tornado blew down many valuable trees in Bartlett Park, after which it lost energy. For about half a mile on either side of the immediate path of the storm high winds caused considerable damage to shade trees, chimneys, etc.

At the weather observatory, about half a mile north of the path of the storm, the wind attained an extreme velocity of 78 miles an hour from the northwest at 5:18 a. m. This record has been equaled only once since the establishment of the weather station in this city in 1910. For several hours preceding the tornado the temperature ranged from 71 to 68, the wind was light from the southwest, south, and east, and the barometer fell slightly, with reading reduced to sea level, approximately 29.71 inches, for more than two hours preceding the storm. At the time of the passage of the tornado the barometer fell slightly and then rose abruptly 0.07 inch. Excessive rainfall for nine minutes, beginning at 5:18 a. m., amounted to 0.42 inch. Thunder and lightning accompanying the storm were moderate.

Two persons were slightly injured and none killed. A conservative estimate of property damage, made by the city engineer, was placed at about $200,000.

RAIN-BEARING WINDS IN THE FAR WESTERN STATES

By THOMAS R. REED

In "Weather Forecasting in the United States" (3) Henry says: "A simple and very general rule for forecasting the weather in the Pacific Coast States is 'southerly winds bring rain; northerly, fair weather' " (p. 119). Probably all meteorologists, in fact all attentive observers of weather phenomena on the Pacific slope, will concur. So infallible appears the operation of this rule and so extensive is the territory over which it holds sway that desire is naturally aroused to determine the actual proportion of cases to which it applies and to define, and if possible explain the exceptions to it, both for the area in general and for particular regions within it. A practicable way of accomplishing this object was suggested by Von Herrmann's paper entitled "The Rain-Bearing Winds of Atlanta, Ga." (1), in which rainfall percentages were diagrammatically represented for each of the eight compass points and for the various months of the year. Weather Bureau stations of the first order within the San Francisco forecast district, which comprises the States of Washington, Oregon, California, Nevada, and Idaho, were asked to contribute these statistics for the 10-year period 1916–1925, and graphic representations developed from their tabulations are reproduced herewith. The only station submitting data based on a shorter period was Spokane, where only 5 years' record was available. Diagrams for each of the 21 stations and for each of the 12 months have been drawn after the Von Herrmann plan, although involving a somewhat dissimilar development of the data.

While diagrams for all the months reveal facts of interest, those portraying the rain-bearing winds of the wet season are most significant. It is evident that due to the shortness of the period for which means were computed, only the data for the rainy season can be relied upon for conclusions. Rainfall during the dry season is so infrequent and relatively so light that, to be representative, means would have to be obtained from an exceedingly long period of observations; longer, in all probability, than any offered by available records. This fact should be borne in mind while inspecting the diagrams, as otherwise very imperfect impressions may result. To cite one case in which this defect is well illustrated, take the San Luis Obispo figures for the nearly rainless month of June. The percentages show northwest to be the rainiest quarter, but inspection of the detailed record reveals the inadequacy of the data, as during the 10-year period there was a total rainfall of only 0.24 inch for all directions, of which 0.08 inch happened to occur while the wind was in the northwest. Another example is furnished by the San Jose table. In this case the meteorologist who supplied the data sought to modify the obvious inconsistency of the dry-season percentages by extending the record to include a 20-year period, and yet we find the maximum rainfall in July occurring with a northwest, or fair weather, wind. Here the limitations of even a 20-year mean for the dry months are clearly illustrated, since the detailed record for July contains a 20-year total of only 0.11 inch, of which 0.08 inch fell during the time the wind was northwest. Similar defects could be pointed out in most of the tables so far as summer conditions are concerned, although the errors become less egregious as we go north along the coast and the amount of summer rainfall proportionately increases.

Obviously, too, with so pronounced a dry season it was impracticable to follow Von Herrmann's method of computing percentages on the basis of annual means and percentages based on monthly means were employed in preference. It was thought that labor would be lessened without material sacrifice of accuracy if station normals for the various months were used instead of actual means for the 10-year period, and most of the station officials made their computations in this way; but a few, feeling that the results thus obtained were misleading, computed means for the particular period involved and secured percentages therefrom. Emphasis must be given to the fact that the percentages refer to the amount of precipitation and not to frequency of its occurrence.

The outstanding fact established by the tables and diagrams is the preponderance of precipitation with south winds. The most casual scrutiny of the data makes this plain. At some stations there are strong southeast and southwest components, and at a few stations one or the other of these components exceeds the southerly direction in the amount of precipitation associated therewith. In most cases, it is believed, the deviation from south or southwest can be accounted for by some orographic explanation. Indeed, such explanation extends to nearly all phases of the diagrams where rains of any considerable amount are found occurring with other than a southerly wind. The exceptions will be found only to confirm the rule that, given a reasonably free exposure, the rain-bearing surface winds are preponderantly from southerly quarters.

As an initial example of such deviation the case of Tatoosh Island, Wash., may be cited. Situated at the entrance to the Straits of Juan de Fuca, it is peculiarly exposed to the east winds which are often found sweeping through them at times when southeast of south winds are blowing at other points on the Washington coast. Not infrequently when this is the case cloud observations at Tatoosh Island show the existence of southeast or south winds at a comparatively low level in the free air above. No other diagram depicts an easterly component which approaches in value this one so conspicuous in the Tatoosh Island diagram, or it might better be said, the existence of an easterly current with rainfall is a marked rarity at the great majority of stations, Tatoosh Island being the most notable exception.

This infrequency of precipitation with east winds in the far West is a phenomenon worthy of special note. While an east wind anywhere in this region denotes an offshore and therefore a relatively dry wind, this by no means dismisses it as a factor in the rain-making process. Both Bjerknes and Shaw, whose situation on a west continental front in the North Temperate Zone makes their observations of peculiar interest to the student of weather forecasting in the North Pacific States, postulate an easterly current or "wedge" over which the rain-bearing southerly wind must ride in order to precipitate its moisture. Such being the case in western Europe, one would naturally expect to find its counterpart on our own western shores. A noteworthy dissimiliarity is presented by our diagrams in this respect, however. Not only is the occurrence of east winds at times of rainfall an abnormality, but its appearance in any of the diagrams may be accounted for, as a rule, by some orographic explanation rather than by the assumption of its existence as a function of the usual cyclonic circulation. This is obviously the case at Tatoosh Island, of which mention has been made, and it is likewise true of winds at other stations farther south.

At North Head and Portland, for example, a small percentage of easterly wind is found, probably induced by the proximity of the great Columbia River gorge, which forms an east-west gap in the Coast and Cascade Ranges. Another station showing a rather prominent easterly component is Fresno. The occasion for this is not altogether obvious, although it may well be found in the disposition of the foothill areas to the north, which probably have a deflecting effect on the predominant rain wind, which is southeast, The hills may cause the rain-bearing wind to assume at times an east-west trend over parts of the upper San Joaquin Valley.

A conspicuous easterly arm is found in the Spokane diagram, but although explanations based on topographic features of the country might account for it, conclusions drawn from the data would be unsafe due to the short period (five years) covered by the record, together with the fact that much of the data are from interpolated records during the winter season, since at that time the recording rain gauge is not functioning.

In the consideration of easterly rain winds perhaps the diagrams which present the most anomalous outlines are those for Los Angeles and San Diego, particularly the former. Flanked by high mountain ranges to the leeward and possessing an unobstructed marine exposure, the region around Los Angeles might be expected to offer ideal opportunity for the occurrence of rain winds from the oceanic or southwesterly quarter. Instead we find a very pronounced opposite component, not only easterly but northeasterly winds being conspicuous in nearly all months, but exceeding other directions in a majority of cases. It is certain that any explanation of this state of things must reside in the configuration of the terrain. This region presents the most radical orographic contrasts to be found in the United States. The mountains rise sheer from base elevations but little above sea level to heights varying between 8,000 and 12,000 feet. The deflective effect produced in gradient winds by these colossal barriers could not be other than profound, although it might not be supposed that a complete reversal of direction would result. It seems probable that at both Los Angeles and San Diego the relation of mountains and plain necessitates the formation of some sort of eddy conforming in a general way to the axes of the principal ranges. Those flanking Los Angeles lie east and west, while those back of San Diego lie north and south, a disposition which may serve to explain a horizontal eddy in the lower atmospheric levels, greatly complicated in its details by the extremely irregular character of the terrain as a whole. At San Diego, it will be noted, although considerable rain occurs with east winds, the predominating rain wind is from the south during all the wet months, whereas at Los Angeles northeast rain winds predominate during the wet months and southerly rain winds are inconsiderable.

But if east and northeast winds at times of precipitation are exceptional, their insignificance is scarcely greater than that of winds from north and northwest quarters, and stations which show this idiosyncrasy are exceptional enough to require individual comment. Two such stations are found in the intermountain region, namely, Baker and Boise. At Baker the northwest component is especially noteworthy, very nearly equaling the preponderant winter direction, which is southeast, and in spring and summer exceeding all others. At both stations the contour of the land would seem to account adequately for the unusual amount of precipitation with northwest winds. It will be remarked that winds of cyclonic origin—that is to say, rain winds—at both stations conform in direction to the main axial line of the respective valleys, being from one of two opposite directions, northwest and southeast.

This subserviency of wind direction to the contour of the valleys is equally apparent in California, where the behavior of rain winds in the Santa Clara, Sacramento, and San Joaquin Valleys well illustrates the point. In the Sacramento Valley, in which Red Bluff and Sacramento are located, there is relatively little rain with northwest winds, since such winds are down-slope. In the San Joaquin Valley, and less pronouncedly in the Santa Clara Valley, represented by the stations at Fresno and San Jose, respectively, the reverse is true, northwest winds at these stations being up-slope winds and consequently contributing a moderate proportion of moisture.

A feature common enough to the diagrams to warrant remark is the increase of rain percentage with northwest winds in the spring and fall of the year. Note will be taken in particular of the relative insignificance of the

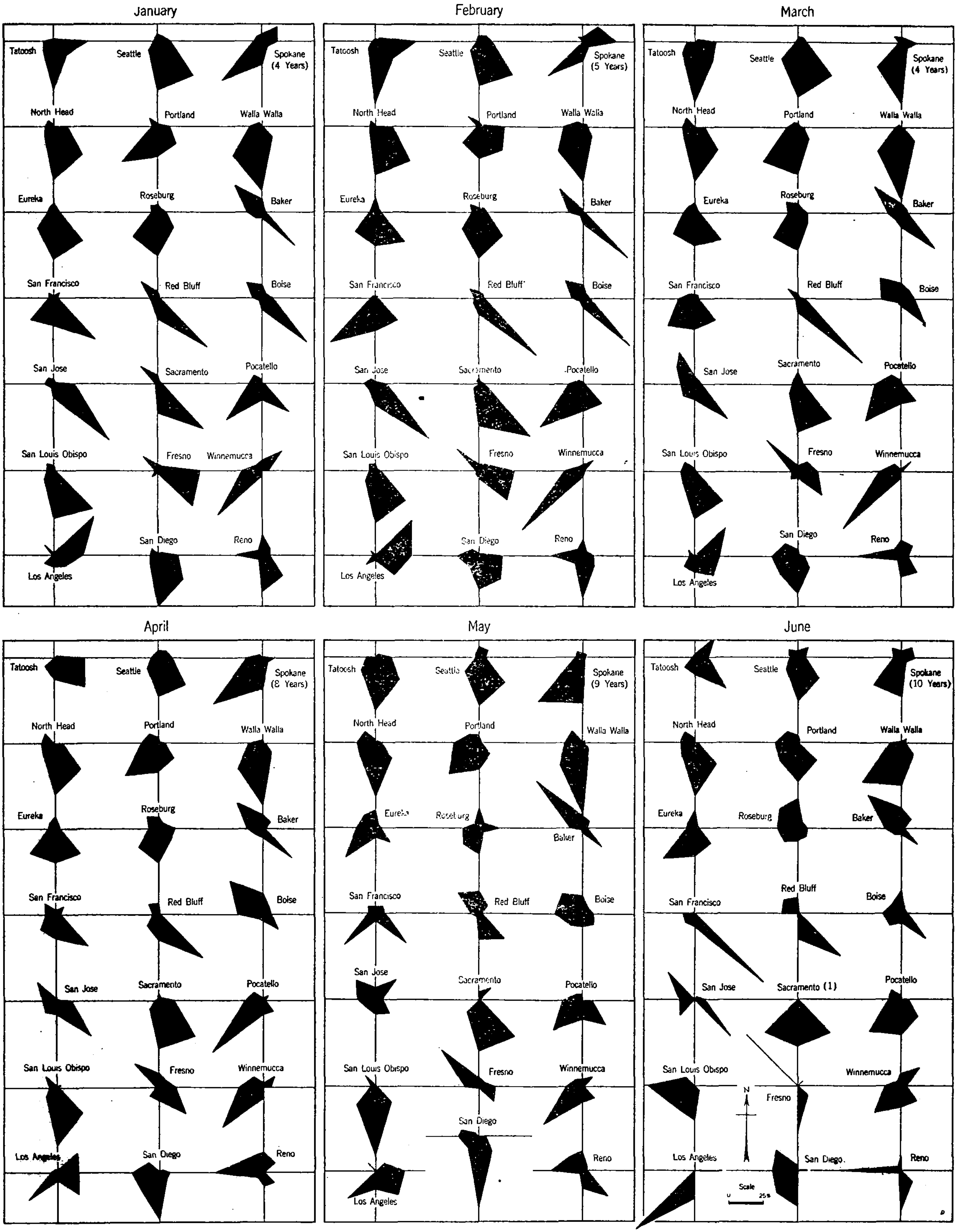

FIG. 1.—Percentage of normal monthly precipitation for each wind direction, January to June, 1916–1925, inclusive

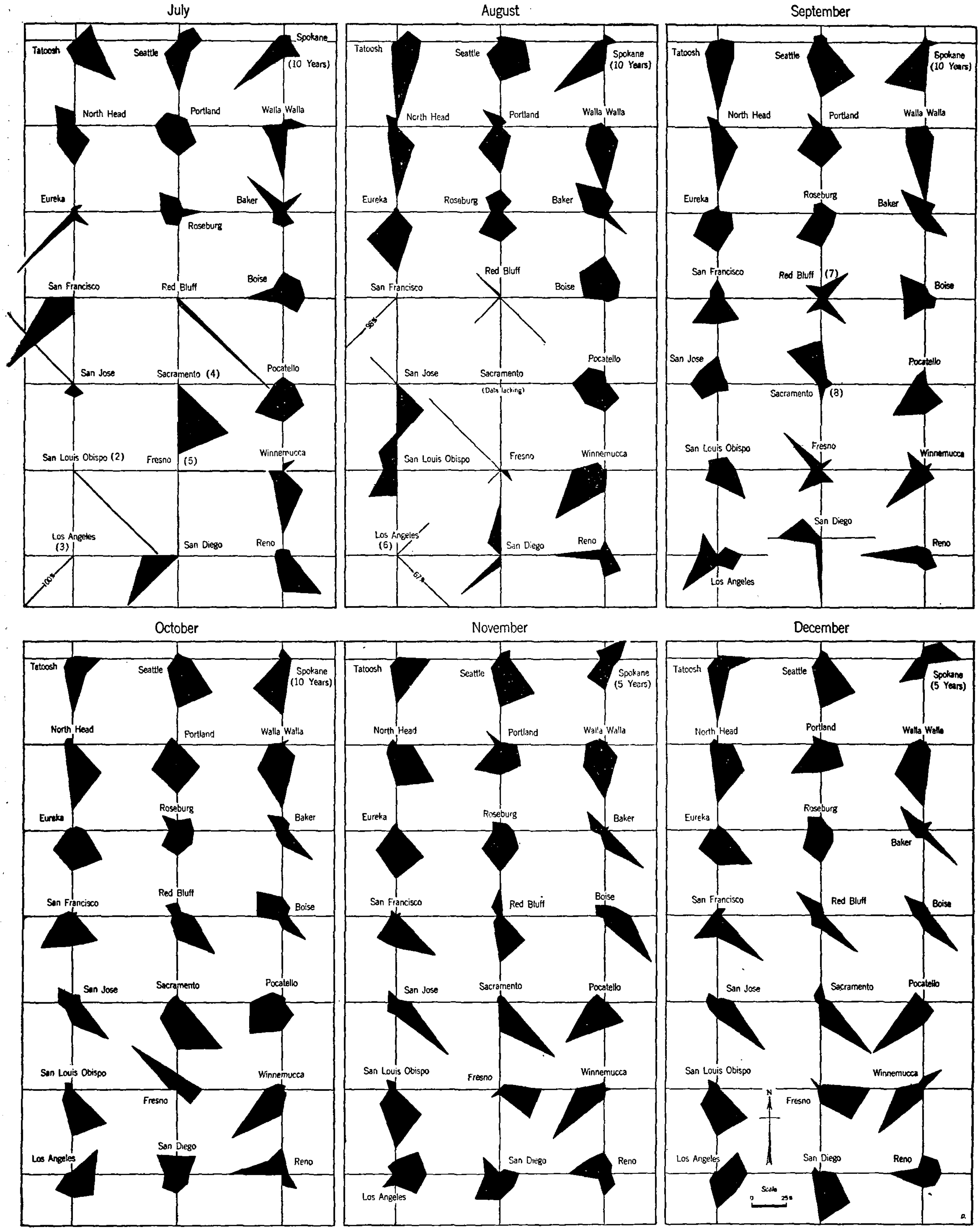

FIG. 2.—Percentage of normal monthly precipitation for each wind direction, July to December, 1916–1925, inclusive

northwest component at San Jose, Fresno, and Boise in winter months as compared with the increase shown in this arm of the diagram in March, April, May, and October. This phenomenon is doubtless attributable to the tendency of low-pressure systems to develop centers over the southern plateau and southern Rocky Mountain regions in the spring and fall months, a fact attested by the investigations of Bowie and Weightman (2), who have shown statistically that "Colorado LOWS" occur with maximum frequency in the spring and fall. The positing of a barometric minimum somewhere near the region assigned to Colorado LOWS is prerequisite to northwesterly rain-bearing winds in the far Western States, whether such rains are explained as of "cold-front" origin, or are attributed to the inclination of the terrain. Both influences are probably at work, but examination of the diagrams leads to the inference that the latter is the more important, since only those stations at which the rainfall with northwest winds is palpably augmented by a convenient attitude of the terrain show amounts which are of any consequence as compared with precipitation associated with winds from the contrary quarter.

While this view will probably not invite contradiction, since it is so widely recognized that rainfall in the far West is subject to orographic control, the diagrams herewith, while substantiating this opinion in general, would seem to oppose it in at least one particular, and that by no means an unimportant one, namely, the small amount of rainfall with westerly winds. The paucity of rainfall with winds from the west is almost as pronounced and uniform as is the case with winds from obviously dry-weather quarters. Perhaps the heterodox aspect of this peculiarity may not impress one who is thinking of rain-bearing winds in terms of cyclonic circulation alone. West winds, aside from their connection with "cold-front" or "squall-line" precipitation, are not ordinarily heavy rain producers. Thus Henry has succinctly stated (3) that "east to southeast winds are preeminently the rain winds of the United States," meaning quite evidently that part of the United States east of the Continental Divide, for he immediately qualifies the statement by specifying the predominance of southerly rain winds in the Pacific States. At the same time he concedes, and apparently with excellent logic, the importance of west winds also as a contributing source of rainfall on the Pacific slope. A glance at a contour map of the western United States will convince one of the plausibility of this. With the great western cordillera lying athwart the path of the westerly winds, laden with moisture from the Pacific Ocean, what could be more natural than to classify such winds as rain producers, as under cyclonic impulsion they are forced up and over the mountain barriers that obstruct their eastward course? It is surprising, therefore, to find this view shattered by the facts so far—that is to say, as they can be deduced from observations at Weather Bureau stations, most of which, to be sure, are at valley points. Perhaps if data were available for the mountain slopes they would tell a different story; quite probably so in the case of canyons cutting into the main ranges in an east-west direction, since in such cases the same conditions in a degree would be present which have been shown to produce rain with northwest winds at Baker, Boise, and Fresno, where the rainfall is augmented by an up-valley course of the air stream.

While other explanations could perhaps be offered to account for the meager rainfall with westerly surface winds over the area represented by observations, a plausible solution is suggested by consideration of the probability that a westerly surface wind implies in general a northwest wind aloft. This assumption is a safe one, since the phenomenon of turning with increase of altitude is especially marked in winds of the western United States, where the lag and distortion in surface currents are accentuated by the exceedingly rugged character of the relief. It will be admitted that a northwest wind in the free air would not be a vigorous rain producer, since it would parallel many of the mountain ranges and attack others at a rather small angle. The converse of this proposition would be true of winds from a southerly quarter. Such winds would bear up against the mountains at an increasing angle with elevation and thus have their natural condensational proclivities increased. On this basis we may conclude that westerly winds *in the free air*, in contrast to westerlies at the surface, are productive of rainfall, since they would be the inevitable concomitant of southwest surface winds, which the diagrams show to be one of the three surface winds most prolific in attendant rainfall.

If the analogy be carried further, we must conclude that the most productive rain winds in the free air are from the southwest, since such winds would be associated with southerly surface winds, and southerly surface winds are shown by the diagrams to be consonant with maximum rainfall. Although southeast winds share in this characteristic, and even predominate in some of the diagrams, it is believed that in a majority of cases this is the result of distortion introduced by topography in what would otherwise be a south rather than a southeast surface wind. This is clearly so in the geological depressions occupied by Red Bluff, Sacramento, San Jose, Fresno, Boise, and Baker, and to a certain extent it may apply at San Francisco, Eureka, Seattle, San Luis Obispo, and San Diego.

In conclusion it may be pointed out that the peculiar rain-making function of southwest winds in the free air is a phenomenon easily recognized by inspection of rain-type weather charts for the far Western States. The isobars on such charts will almost invariably call for a southwest current at moderately high altitudes over the area where precipitation is occurring in considerable amounts. Although this assertion may not provoke incredulity, two isobaric charts are submitted in support of it, depicting the average barometric pressure between the 110th and 155th meridians, west longitude, and the related rainfall in the Pacific forecast district. The same calendar month has been chosen, viz, October, of two consecutive years. The choice was governed primarily by recognition that the months in question presented opposite types of weather for the district as a whole, October, 1924, being unusually moist and October, 1925, dry. It was consequently believed that isobars derived from average pressures for two such months could be depended on to illustrate with least deception the general air circulation responsible for such contrary effects.

It will be observed that for the wet month the trend of the isobars implies a preponderance of southwest winds; that is to say, winds paralleling the isobars, in the free air contiguous to the area where precipitation is in excess of the normal, while for the dry month the isobars call for free-air winds from northerly quarters over the greater part of the district. The excess of moisture in parts of Idaho, Nevada, and southern California on the dry-weather chart is altogether attributable to LOWS of the plateau or Colorado type which were generated on the southeast side of the California-Hawaii high-pressure system, the existence of which is not altogether effaced even by their absorption into mean pressure values for the month. The significant feature of this chart, however, is the abnormal position and axial attitude of the oceanic high-pressure system, which is so disposed as to imply the displacement of southwesterly or rain-bearing air currents into quite high latitudes.

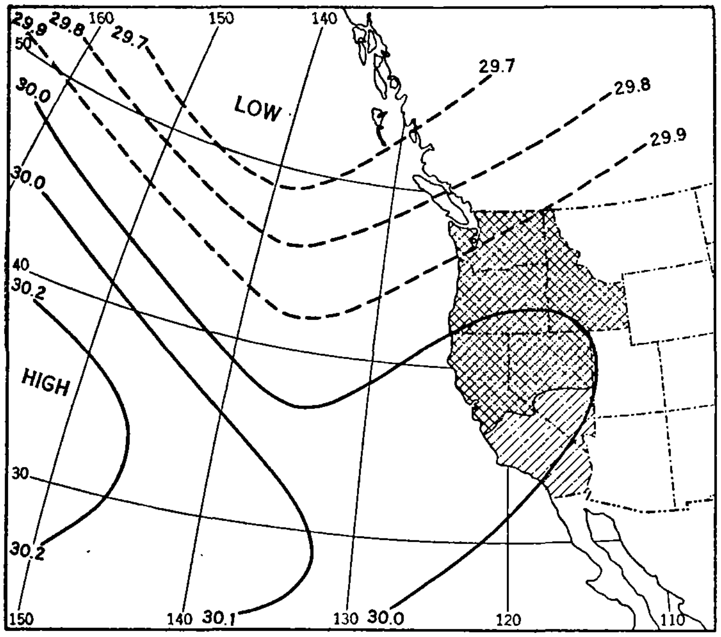

FIG. 3.—October, 1924. Mean 8 a. m. pressure, 7 a. m. at sea, 75th meridian time. A notably wet month over much of the Pacific forecast district. Region of *subnormal* precipitation shown by hatched lines, *supernormal* by cross-hatched lines

In contrast to this pressure arrangement is that for the preceding October, when the oceanic high-pressure system lay far to the west, thus permitting easy access in lower latitudes of winds from the southwest or rainy quarter. The effect of the ingress of air from this quarter was so marked that it can not be appreciated by the mere statement that the ensuing rainfall exceeded the normal over a large area. The excess was so extraordinary that in Washington comparative data showed the month to be the wettest October since state-wide records had been kept, a period of 35 years. In Oregon it was the wettest October for the State as a whole since 1900, and for the western division the wettest since 1890. In California the state-wide average for this October had not been equaled since 1899, while for certain localities along the north coast the amounts exceeded any October rainfalls of record.

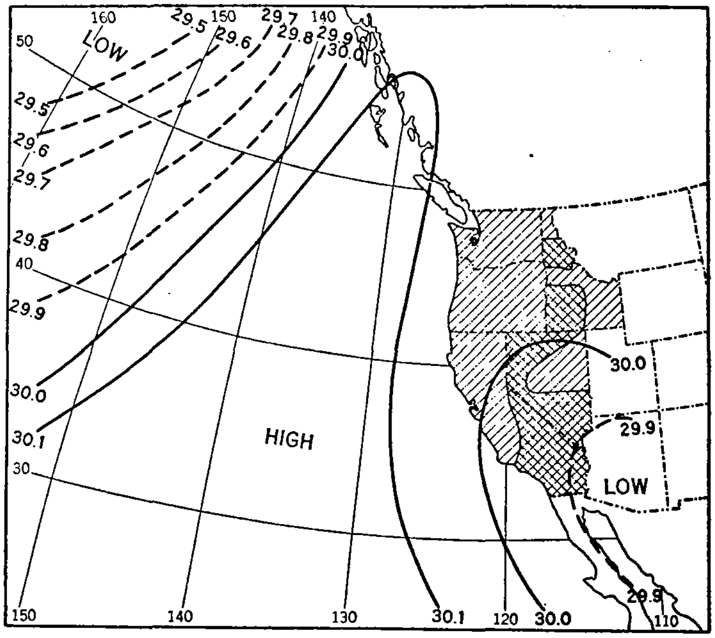

FIG. 4.—October, 1925. Mean 8 a. m. pressure, 7 a. m. at sea, 75th meridian time. A dry month over much of the Pacific forecast district. Region of *subnormal* precipitation shown by hatched lines, *supernormal* by cross-hatched lines

NOTES TO FIGURES 1 AND 2

[1] Total amount, all directions, 0.25 inch.
[2] Only one rain in 10 years; amount, 0.01 inch.
[3] Total, 0.09 inch.
[4] Total amount, all directions, 0.08 inch.
[5] 100 per cent east.
[6] 33 per cent northeast, total 0.01 inch; 67 per cent southeast, total 0.02 inch.
[7] Northeast rain not typical; caused by freak storm of September, 1918; 4.56 inches falling while wind was northeast.
[8] Abnormal north and northwest components caused by rainstorm of September, 1918.

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(2) MONTHLY WEATHER REVIEW, Supplement No. 1. Bowie and Weightman. Types of Storms in the United States and Their Average Movements.
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TWELVE YEARS OF LONG-RANGE FORECASTING OF PRECIPITATION AND WATER LEVELS

By AXEL WALLÉN

[Stockholm, Sweden]

(Translation by B. M. Varney from the Köppen-Heft der Annalen der Hydrographie, 1926)

Each year since 1915 I have published, usually in February, an advance computation of the probable tendency of precipitation and water level in Sweden for the ensuing 12 months. In view of the very considerable period during which these long-range forecasts have been made and tested, I wish to give in what follows a short review of the results.

With regard to the methods used I shall speak briefly, since the principles have been set out more in detail elsewhere.[1] They are based on the existence of a period a few years in length, of an average value of some 28 months, and on a period that averages 11 years, which shows also two secondary maxima and minima within this 11 years. This latter period is very important in the case of lakes that have large storage capacity, e. g., Lake Wenner; on the other hand, its significance is relatively less conspicuous in the case of precipitation changes and as regards the levels of waters not characterized by great reservoirs of that sort.

The method I have found most useful in preparing the forecasts here set forth may be described most simply as a study of the variations of the elements involved, the yearly period of each having first been eliminated; after such elimination these elements showed a period most clearly, the average length of which is 28 months, with, however, considerable irregularity.

If we designate the original monthly values as

$$a_1\, a_2\, a_3\, \ldots\ldots$$

(smoothed by forming running five-month values), and

[1] Axel Wallén, Vanerns Vattenstandsvariationer. Meddelanden fran Hydrografiska byran. 1. Stockholm, 1910.—Les previsions des niveaux d'eau et des debits en Suede. Geograf. Annaler h. 3. 4. 1919.